

Atmospheric Profiles, Clouds and the Evolution of Sea Ice Cover in the Beaufort and Chukchi Seas

Dale A. Lawrence
Aerospace Engineering Sciences
University of Colorado
Boulder, CO 80309

phone: (303) 492-3025 fax: (303) 494-7881 email: dale.lawrence@colorado.edu

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LONG-TERM GOALS

This is a collaborative research project with the University of Washington (Axel Schweiger, PI). Its purpose is to examine the role of sea-ice and cloud interactions in the retreat of the seasonal ice zone (SIZ). As sea ice retreats further, changes in lower atmospheric temperature, humidity, winds, and clouds are likely to result from changed sea ice concentrations and ocean temperatures. These changes in turn will affect the evolution of the SIZ. An appropriate representation of this feedback loop in models is critical if we want to advance prediction skill in the SIZ. The overall project is an integrated observation and modeling program aimed at understanding the interplay of atmosphere, ice, and ocean in the SIZ of the Beaufort and Chukchi seas (BCSIZ). It will take advantage of routine Coast Guard C-130 domain awareness missions that take place at two-weekly intervals from March through November.

This portion of the overall project will contribute to technology development by adapting and deploying a new generation of truly expendable (<\$700) micro-aerial vehicles (Data Hawk and SmartSonde) designed to obtain detailed high-vertical-resolution temperature, humidity and wind profiles and cloud layering information that cannot be obtained with traditional dropsondes. Our vision is that these vehicles will deliver new, inexpensive measurement capabilities for research and operational purposes in the data sparse region of the BCSIZ as well as other regions of the globe.

This project provides a unique and cost-effective opportunity to establish a fully integrated observation and modeling program that builds on existing experience and data in a region that is poorly understood and is undergoing rapid change. Improved prediction of the marine environment in this area may be critical for future Navy operations.

OBJECTIVES

The main objective of the University of Colorado portion of the project is to adapt an existing low cost, expendable small unmanned aircraft system (sUAS) called the DataHawk for air-deployment from a

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Coast Guard C-130 to measure temperature and humidity profiles and cloud top and base heights in the seasonal ice zone.

APPROACH

[technical approach, key individuals at your own or other organizations]

The approach builds on an existing low cost capability to measure in-situ atmospheric data, consisting of a small unmanned aircraft system (DataHawk) developed at the University of Colorado. The Data Hawk (Figure at right) is an electrically powered miniature UAV equipped with a thermodynamic sensor package measuring pressure, temperature, humidity, turbulence, and mean winds. The Data Hawk type of vehicle occupies a niche in between a drop or balloon sonde, which is low cost but cannot be guided, and a typical UAV, which provides guidance flexibility but uses costly avionics and commercial aerospace components. The Data Hawk vehicle and its avionics were designed with low cost and atmospheric sensing applications in mind. It uses a custom autopilot (Figure 5), developed by the investigators [Pisano *et al.*, 2007], using aerodynamics and control principles to minimize the flight control complexity, significantly reducing the size and cost of electronics and sensor components. It takes advantage of low cost components for the airframe and electric propulsion (from high-volume manufacturing for the radio control hobby industry). The flight control utilizes newly developed, robust, vector field guidance strategies [Lawrence *et al.*, 2008] to automate flight and simplify the ground station interface so that pilot training is not necessary to operate the vehicle. Currently, this vehicle and the flight control system are produced in small quantities at a unit cost of \$700, more than an order of magnitude lower than other UAVs with similar capabilities, such as the folding wing BAE Coyote.



The sensing and avionics system on the DataHawk will be adapted to a folding-wing airframe that can be deployed from a Coast Guard C-130. This new vehicle, called the SmartSonde, will be expendable, similar to a dropsonde, but can be guided to regions of interest and can remain aloft, climbing and descending, for approximately 1 hour to obtain high-resolution atmospheric measurements. This work will be carried out at the University of Colorado by a graduate student in Aerospace Engineering Sciences, under the direction of PI Dale Lawrence.

WORK COMPLETED IN FY 2013

Accomplishments toward the tasks outlined in the project proposal are detailed below.

- **Task 4: Develop, integrate and test long range transmission using the DataHawk.**

Work in FY 2012 identified options for longer range data communications, but none of these appeared workable enough to pursue. Instead, a concept of operations for this program was developed that utilizes the flight plans for Coast Guard domain awareness flights and enables the existing communication system to be used. The SmartSonde is dropped at high altitude (i.e. above the cloud deck) by the C-130 on the outbound leg of the sortie flying north along the 150° W longitude meridian (see Figure 1). The SmartSondes will then fly climb/descend

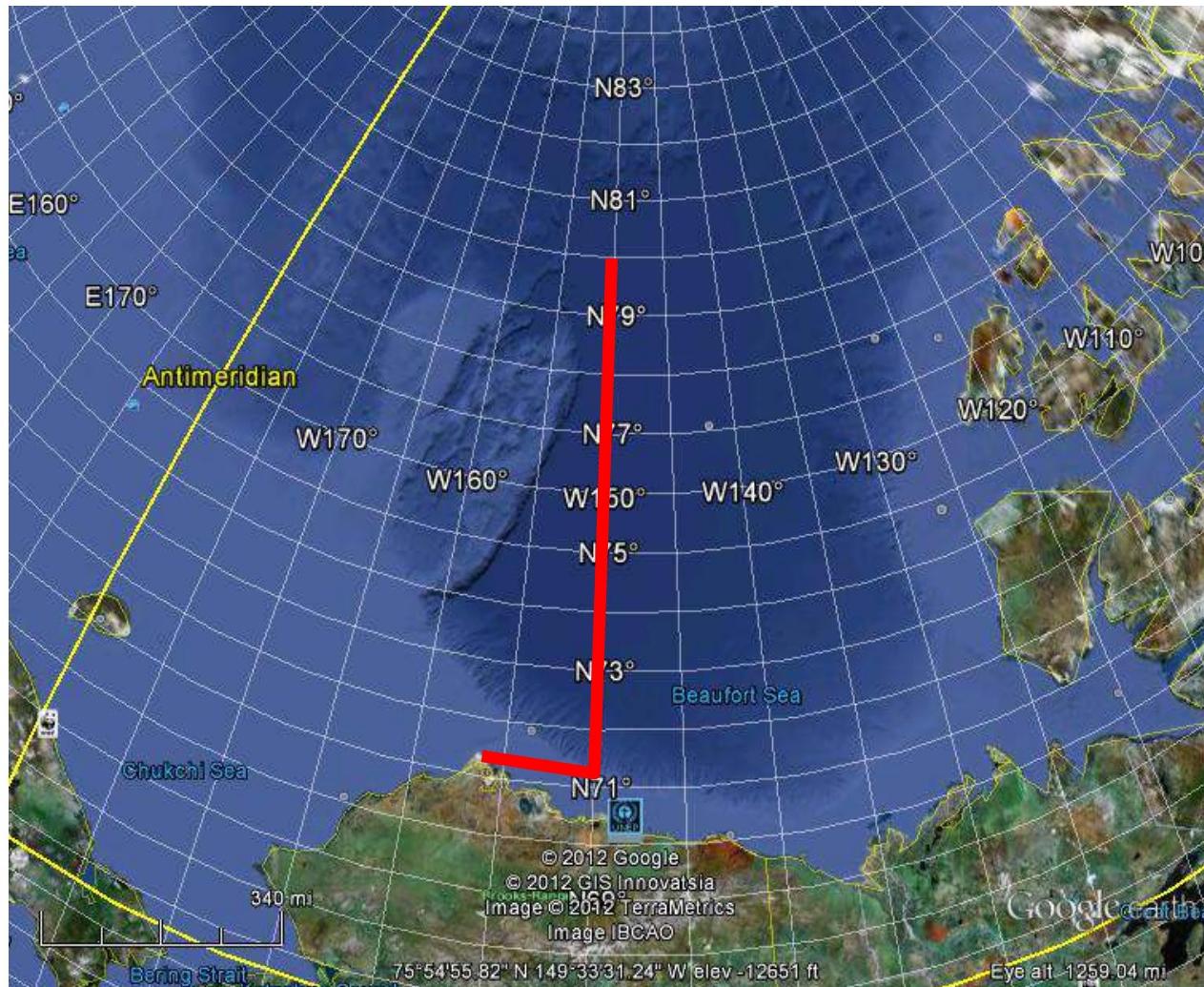


Figure 1: Coast Guard Domain Awareness Flight path to be used in the SIZRS project.

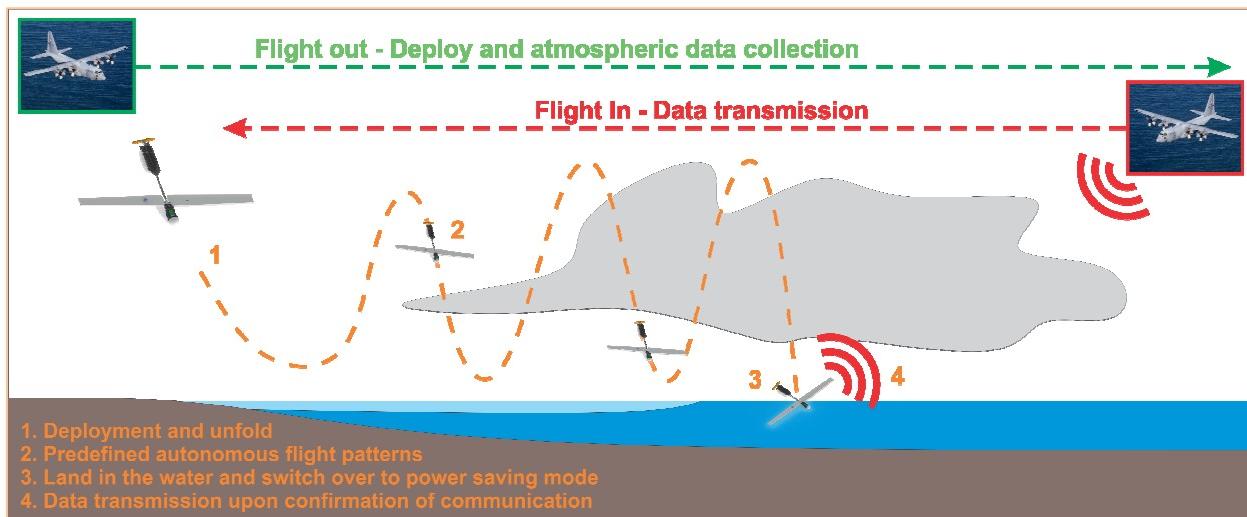


Figure 2: SmartSonde concept of operation: drop from the C-130 on the outbound leg and recover its recorded data on the inbound fly-over.

profiles through the cloud layers until their batteries are depleted (estimated to be about 1 hour

profiles through the cloud layers until their batteries are depleted (estimated to be about 1 hour each). The SmartSonde then lands in the water and waits for the C-130 to return on its inbound leg. Recorded data is then transmitted to the C-130 once it comes in radio range, about 5 km. This approach avoids constraints on the C-130 flight (e.g. to loiter over the SmartSondes until they land), and avoids the need to communicate over long, over the horizon distances.

- Task 5: Design a tube launch canister and release mechanism for the SmartSonde.**

The original folding wing SmartSonde design has been revised to improve ruggedness and flight stability, and to simplify manufacture and reduce weight (Figure 3). In particular, the wing folding/latching mechanism has been re-designed using simple plate elements, rather than the complex milled shape originally developed (Figure 4). A more reliable unfolding mechanism has been developed, along with a more powerful tail motor and larger folding propeller. A design for the tube launch canister and release mechanism has been detailed, consisting of a spring-loaded clamshell tube released by existing nylon line cutter technology. This releases a parachute that slows the descent. A second line cutter then releases the spring-loaded wing unfolding mechanism and the parachute, enabling the vehicle to fly normally.



Figure 3: Redesigned SmartSonde vehicle, folded .



Figure 4: Simplified folding/latching wing mechanism.



Figure 5: SmartSonde at flight test range .

- **Task 9: Flight test SmartSonde in restricted air space using balloon launches**
The SmartSonde vehicle was first test flown under a bungee launch system and manual (R/C) control. After several iterations on the elevator center position, a suitable trim state was obtained. The vehicle was then outfitted with an existing DataHawk autopilot (CUPIC) and autonomous flights were conducted at the CU Boulder South flight range after launching under R/C control. See Figure 5. No wing unfolding deployments were conducted, but the ruggedness of the design was tested through many such take-offs and landings in rough terrain.
- **Task 10: Validate cloud base sensing methodology using SmartSonde in restricted airspace**
Two approaches were pursued to validate the IR sensing system. An existing DataHawk vehicle with this sensing system was flown in conjunction with a commercial ceilometer (Vaisala CL31) into a low cloud deck at Oliktok Pt. Alaska in R-2204 restricted airspace (as a measurement of opportunity during the recent MIZOPEX field campaign). An alternative approach was developed by incorporating the proposed IR sensors and ground-sky temperature difference algorithm into a tethered balloon borne payload (Figure 6). This approach allows the balloon to repeatedly ascend and descend through the cloud base under quiescent sensor attitude conditions. The same ceilometer was used to provide a cloud base reference measurement, as well as visual markings of altitudes where the balloon and its payload disappeared into the cloud base.



Figure 6: Balloon-borne IR sensing payload .

RESULTS FROM FY 2012

- Improved wing spar designs with elongated spar-to-wedge plate coupling provided excellent wing strength. In conjunction with the crash-release mechanism, the vehicle survived many bad launches (before the vehicle was properly trimmed) and many hard landings with no damage to the vehicle.
- Larger motor and propeller designs provided adequate thrust for most flight situations, although fast climb rates (above 1 m/s) could not be achieved. These components may need to be further

- enlarged to satisfy the new CONOPS where the SmartSonde repeatedly climbs and descends through cloud layers.
- The re-designed SmartSonde proved to fly well with adequate thrust and aileron authority. Elevator authority was somewhat weak, so elevator area will be increased in the final version.
 - Cloud base sensing with the DataHawk in Alaska (as part of the MIZOPEX campaign) was inconclusive. One flight was carried out, where the plane ascended into the cloud base using an autopilot that employs the same IR sensing system for bank angle flight control as proposed for cloud margin sensing. The plane underwent large bank oscillations as it entered the cloud base, due to errors in bank sensing caused by lateral IR differences in the cloud layer lower boundary. As a result, the ground-sky IR temperature differences due to cloud penetration could not be distinguished from the signal produced by large bank angle excursions, and the IR cloud margin sensing technique could not be validated. Unfortunately, further such flights to better understand the anomalous behavior could not be accomplished in this campaign due to schedule conflicts and unfavorable weather conditions.
 - One flight of the balloon-borne instrument was conducted in Colorado. This was also inconclusive. The balloon-borne sensor worked well, with a well-behaved attitude, avoiding the confusion between bank excursions and cloud penetration in the IR temperature signal observed in the DataHawk flights in Alaska. However, in this experiment the cloud deck was too high to reach with the tether length available, so cloud base penetration was not achieved. Since this system does not need restricted airspace to operate, there are expected to be many more opportunities to repeat this measurement. These will be conducted either in Colorado, driving to sufficiently high altitudes in the mountains to reach the cloud base if necessary, or in Seattle where cloud bases are regularly seen at low altitudes.

IMPACT/APPLICATIONS

The new SmartSonde folding wing design enables the slow flying sUAS to be deployed in a variety of ways from much higher speed delivery vehicles, including 1) sonobuoy tube ejection, 2) hand dropping from the rear ramp (e.g. for the C-130), 3) release from wing pods, and 4) release from fuselage stores pods or bays. It also enables ground or water launch from bungee or air gun launchers. This provides a flexible ability to deliver the sensing system from a variety of carriers, expanding the ability to take atmospheric measurements at low cost over wide areas.

RELATED PROJECTS

The Marginal Ice Zone Process Experiment (MIZOPEX) seeks to explore the use of unmanned aircraft systems (UAS) to provide a complementary ability to make surface and sub-surface measurements in the Arctic marginal ice zone. The DataHawk vehicles that were precursors to the SmartSonde in this project are being re-purposed in MIZOPEX as one-way self-deploying surface sondes (SDSS) to land in the ocean in and near the ice margins to measure surface and subsurface sea temperatures over a ten day period. See <http://ccar.colorado.edu/mizopex/index.html> for more information.

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